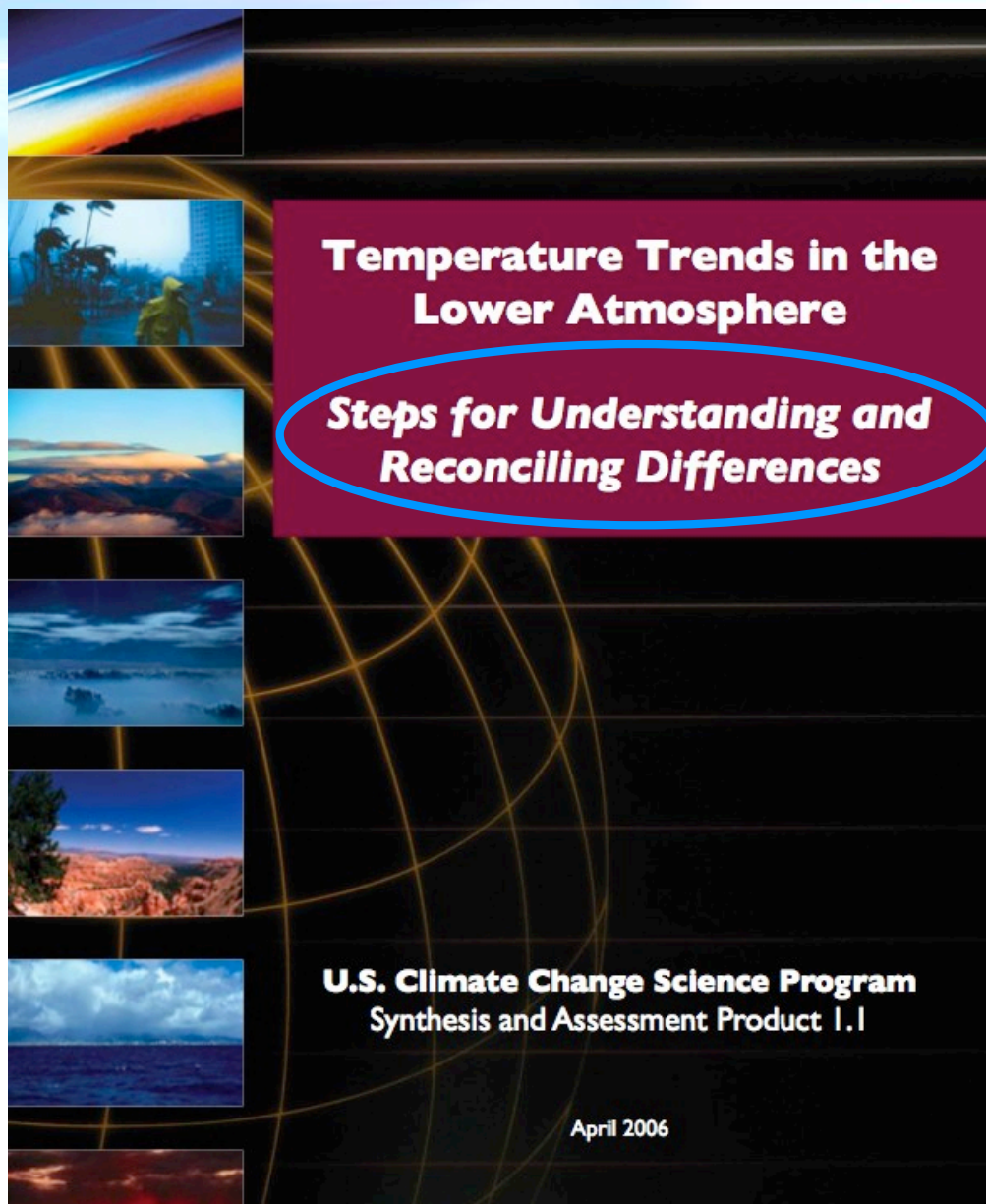# 3-Way Comparison between AIRS, ECMWF and GPS Temperatures in Upper Troposphere and Stratosphere

Tom Yunck, Eric Fetzer, Anthony Mannucci, Chi Ao, Bill Irion,
Brian Wilson and Gerald Manipon

Jet Propulsion Laboratory
California Institute of Technology

AIRS Science Meeting
Pasadena, CA

29 March 2007

Temperature Trends in the Lower Atmosphere

Steps for Understanding and Reconciling Differences

U.S. Climate Change Science Program
Synthesis and Assessment Product 1.1

April 2006

Some Key Points

- Adjustments to data are generally subjective and can be large compared to the actual trend.

- Reported trends vary considerably between groups *using the same data* owing to differing adjustment methods.

- Most *models* predict greater warming in the troposphere; most *observations* show greater warming at the surface. *The likely cause is errors in the tropospheric observations.*

- Recent adjustments have brought satellite observations into closer agreement with models.

- "Satellite observations tend to be bias-corrected to the model." (*Healy & Thépault*, 2006) [ECMWF]
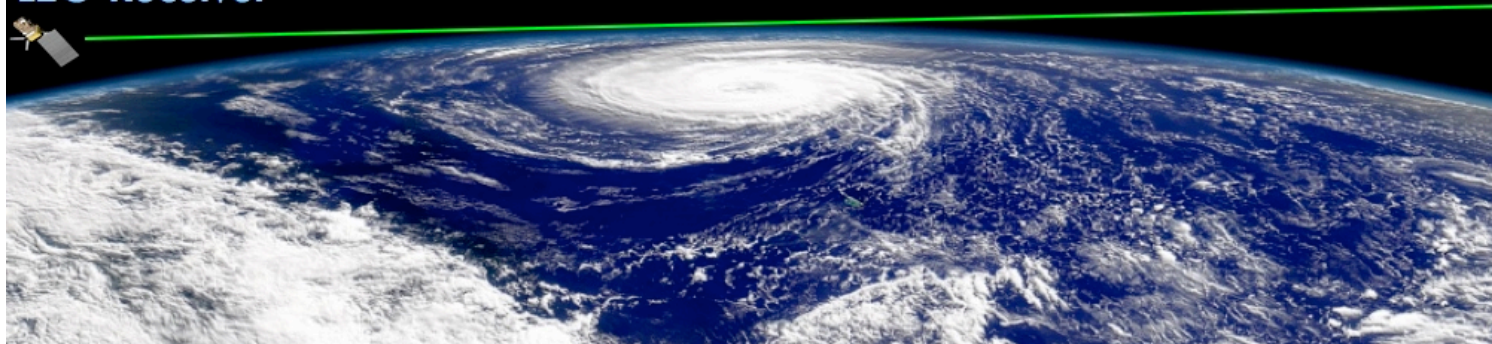
One Approach

GPS Atmospheric Occultation

- High resolution profiles of:
  - Bending angle
  - Refractivity
  - Density
  - Pressure
  - Temperature / Moisture
  - Geopotential heights
- Temporal and spatial averages, 2D maps
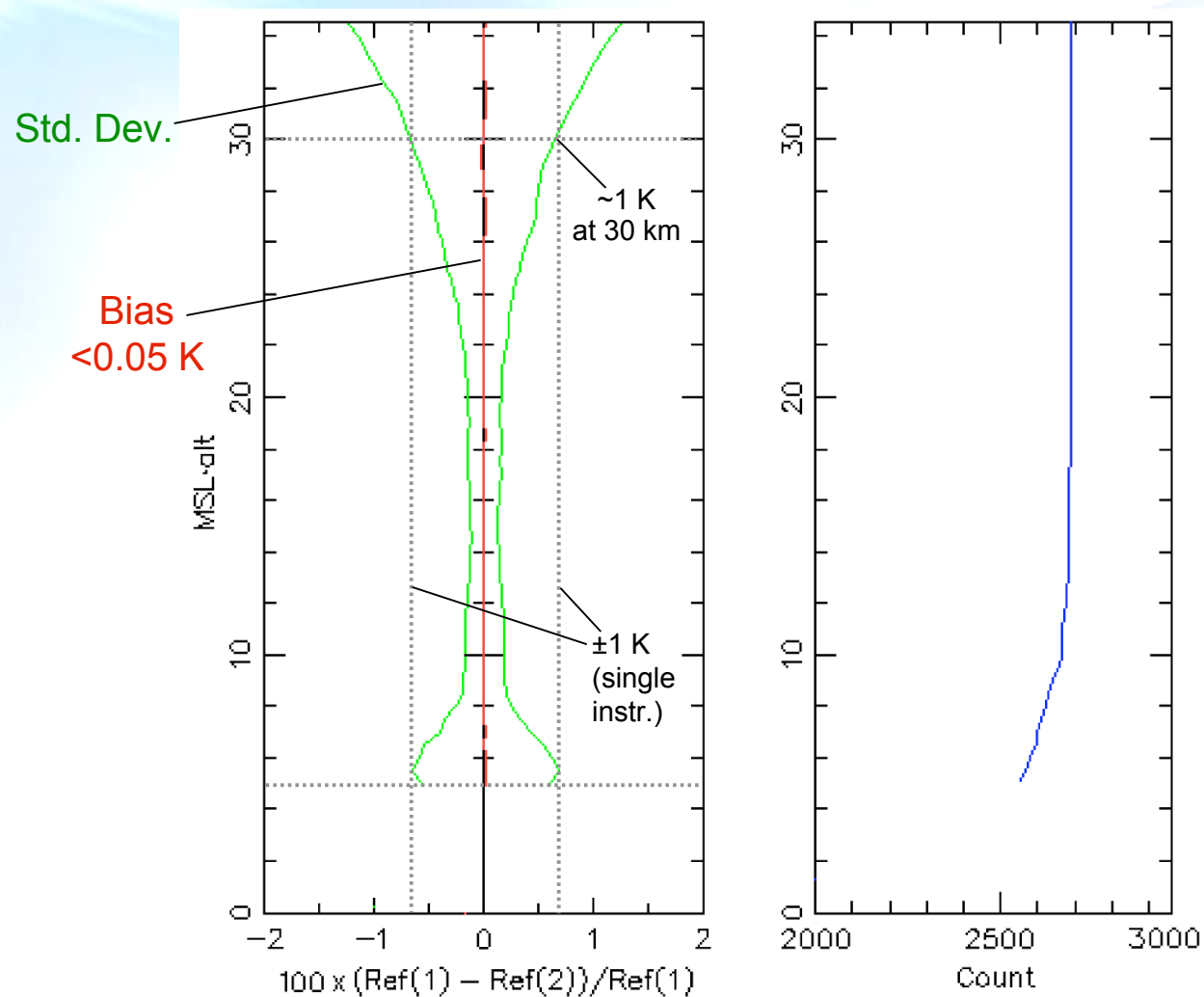- Global pressure contours, gradients, and geostrophic wind fields

LEO Receiver
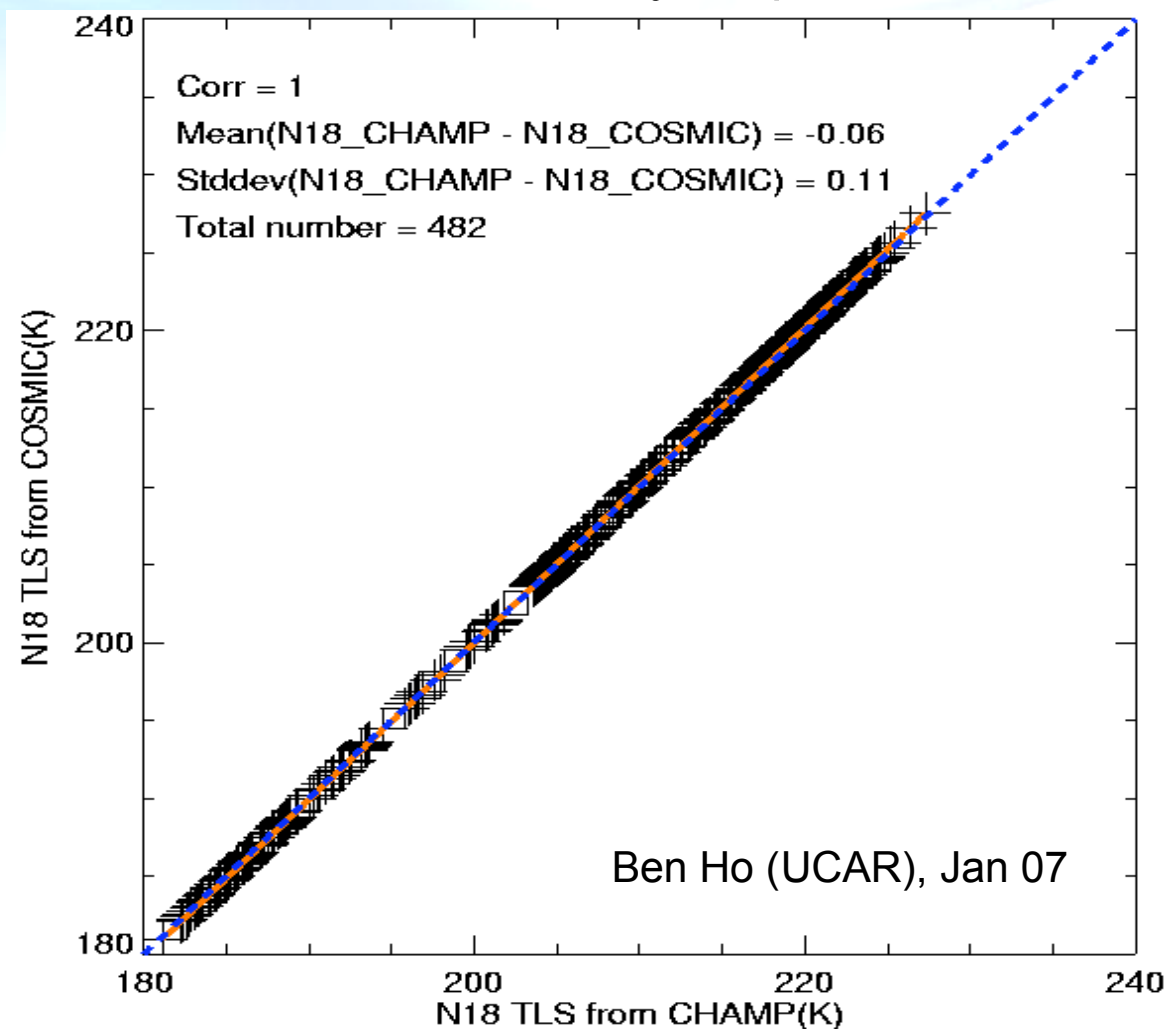
To GPS ⟶

GPS-GPS Comparison Stats from COSMIC

Std. Dev.

~1 K
at 30 km

Bias
<0.05 K

±1 K
(single
instr.)

MSL-alt

$100 \times (Ref(1) - Ref(2))/Ref(1)$

Count

No cloud or
weather
sensitivity

No corrections
or calibrations
required

Performance
traceable to an
absolute SI
standard

Ben Ho (UCAR), Jan 07

TLS Comparison with GPS Sensors
Launched 6 yrs Apart

Corr = 1
Mean(N18_CHAMP - N18_COSMIC) = -0.06
Stddev(N18_CHAMP - N18_COSMIC) = 0.11
Total number = 482

Ben Ho (UCAR), Jan 07

N18 TLS est. from COSMIC v. N18 AMSU TLS est. from CHAMP

Modeled GPSRO Temperature Sigma

Error Model for Mid-Latitude GPSRO Profiles

Modeled GPS
Temperature Sigma
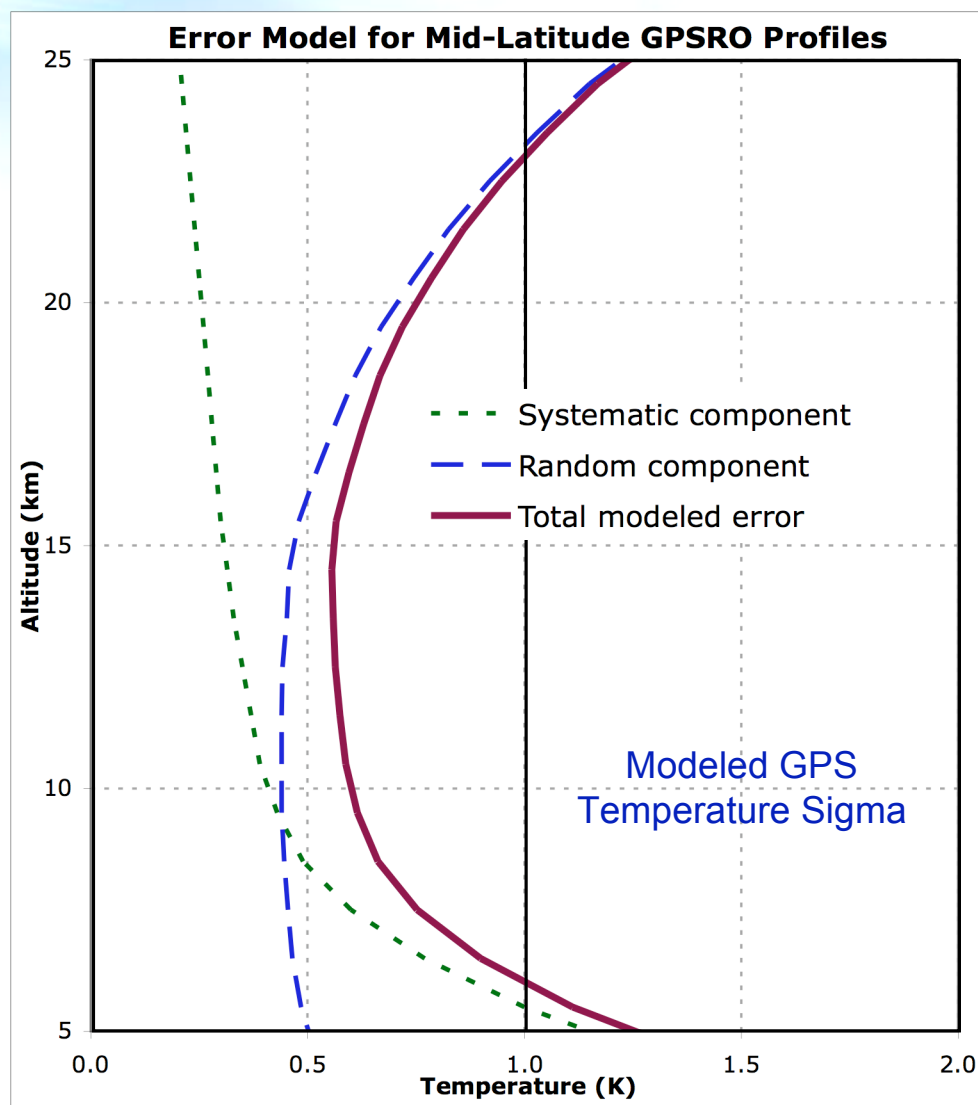
Controlled Three-Way Comparison:

- AIRS-ECMWF-GPS temperatures
- Common set of 3-way match-ups
- For all of 2003 (Champ, SAC-C)

ECMWF "Sweet Spot"
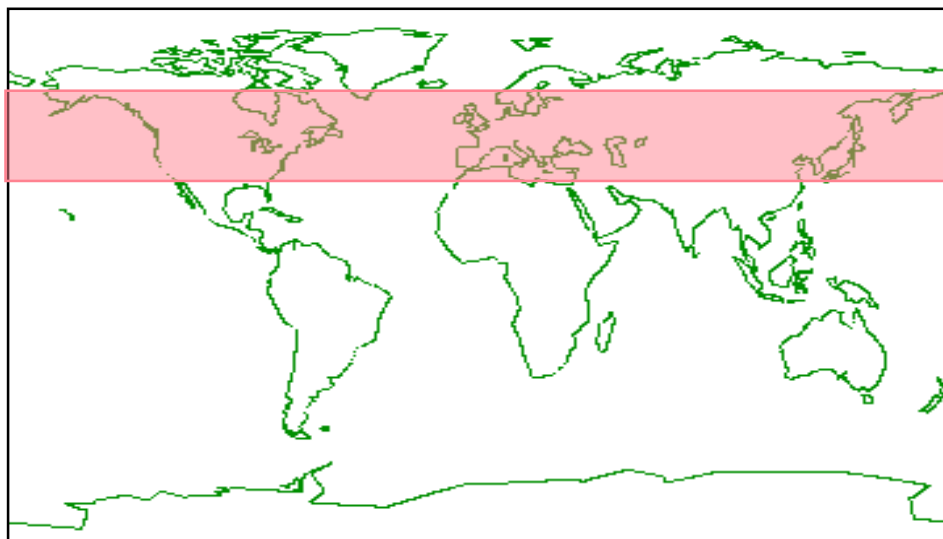
First comparisons:
30°-60° North
("Mid North")

Match-up criteria: <200 km, <2 hrs apart

Pairwise RMS deviations

Mid North Pairwise RMS Deviations, 2003

Legend:
- — · — AIRS-ECMWF
- — — GPS-ECMWF
- —— GPS-AIRS
- - - - GPS Model Deviation

Match-ups: 766
AIRS Quality: 0, 1
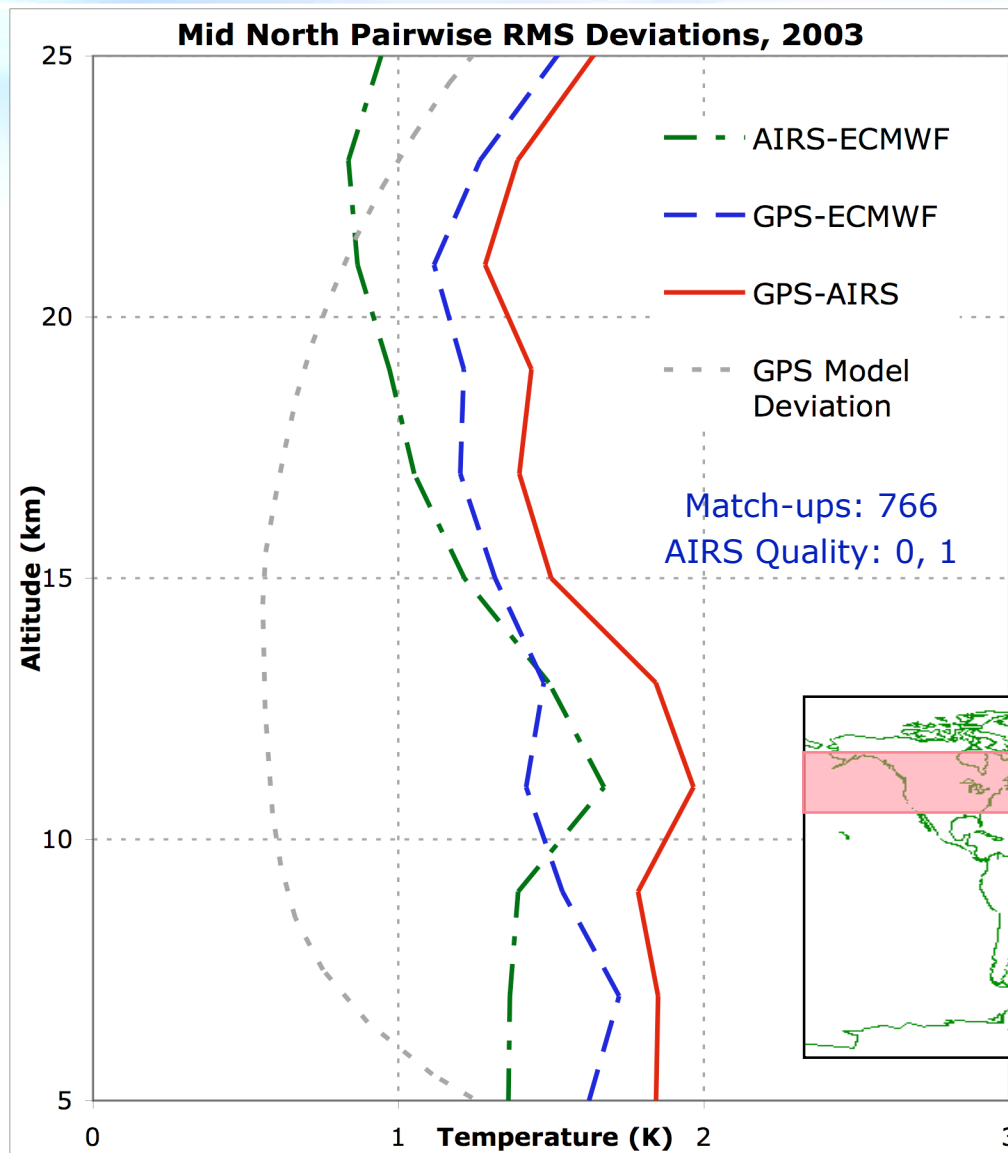
A Puzzle

Derived AIRS & ECMWF RMS deviations

Derived AIRS & ECMWF RMS deviations

Derived AIRS & ECMWF RMS deviations

Some Observed and Derived RMS Deviations

Legend:
- Actual AIRS-ECMWF Dev
- Derived ECMWF Deviation
- Derived AIRS Deviation
- Expected AIRS-ECMWF Dev
- Modeled GPS Deviation
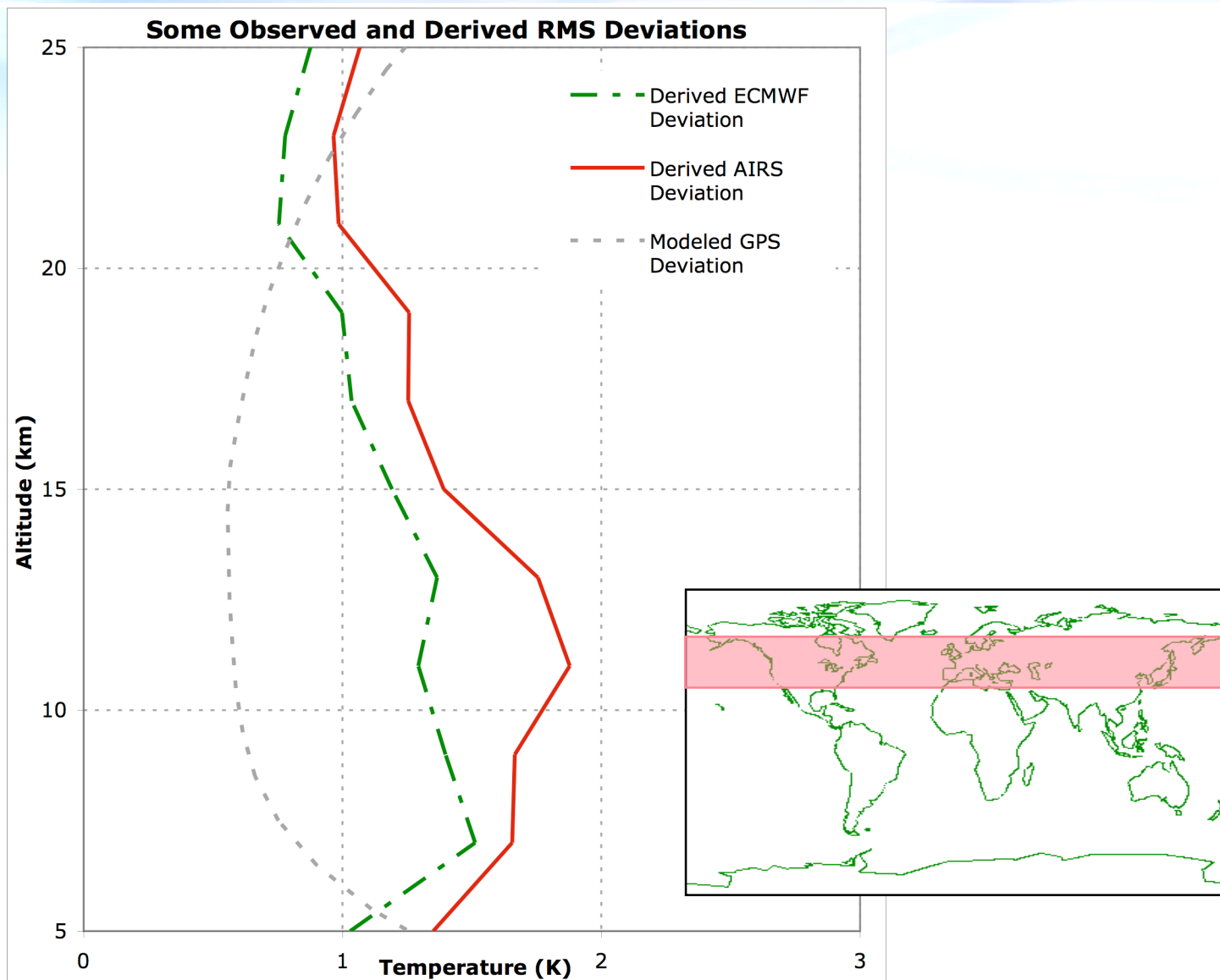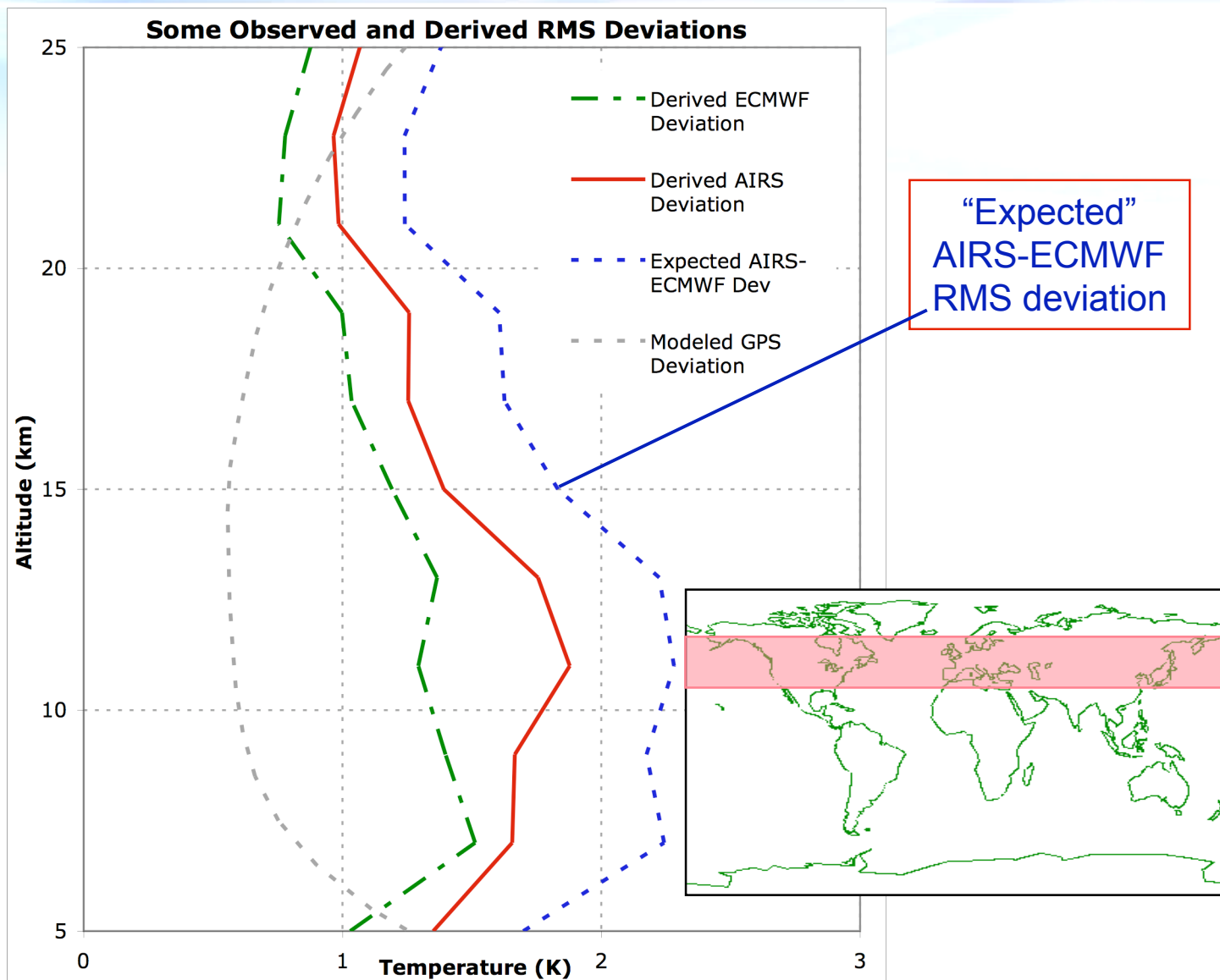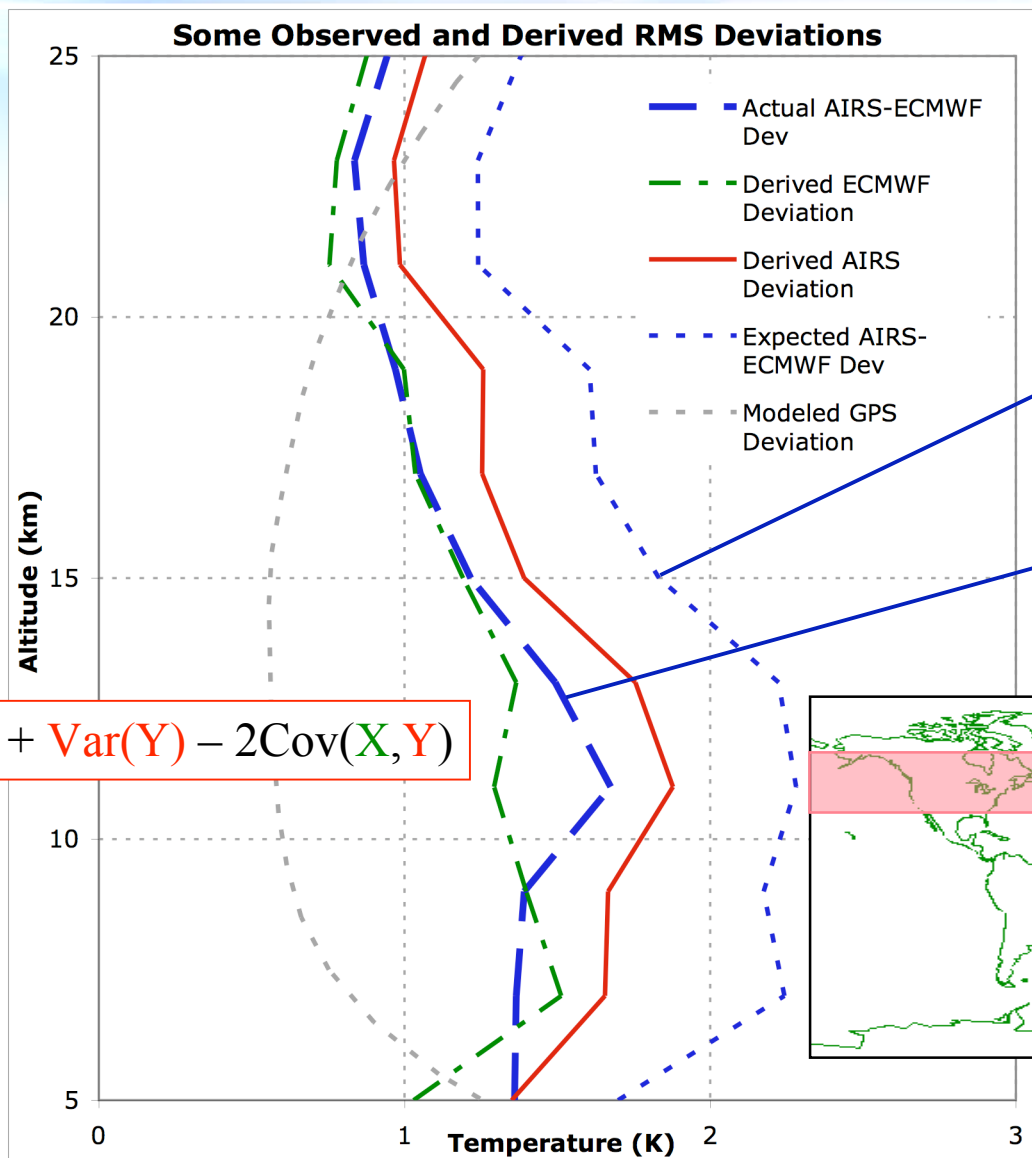
"Expected" AIRS-ECMWF RMS deviation

Actual AIRS-ECMWF RMS deviation

$$Var(X-Y) = Var(X) + Var(Y) - 2Cov(X,Y)$$

Altitude (km)

Temperature (K)

Derived AIRS & ECMWF RMS deviations
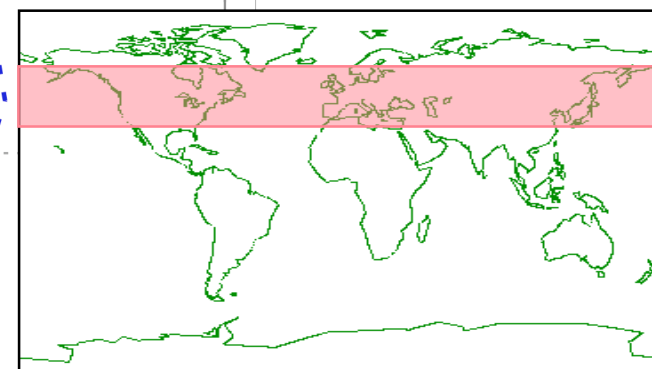
Mid North Deviation & Covar Estimates

AIRS-ECMWF "Covariation"

- – · – ECMWF RMS Deviation
- —— AIRS RMS Deviation
- – – – AIRSxECM Covariation
- ······· GPS RMS Deviation

Match-ups: 766
AIRS Quality: 0, 1

Altitude (km)

Temperature (K)

Derived AIRS & ECMWF RMS deviations

Mid North Deviation & Covar Estimates

AIRS-ECMWF Corr. Coeff.

- - - GPS RMS Deviation
- - - AIRS x ECM Covariation
- · - ECM RMS Deviation
—— AIRS RMS Deviation
—— Correlation Coeff, AxE

Match-ups: 766
AIRS Quality: 0, 1
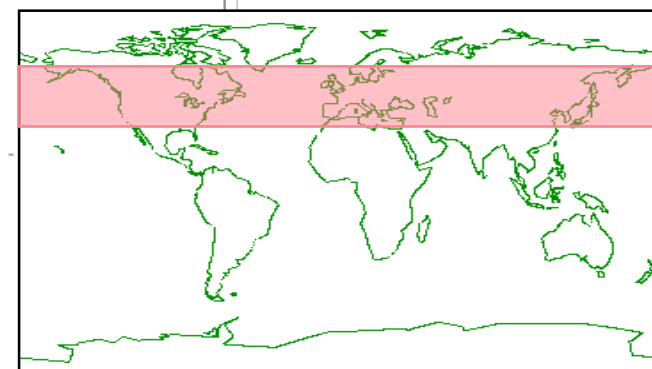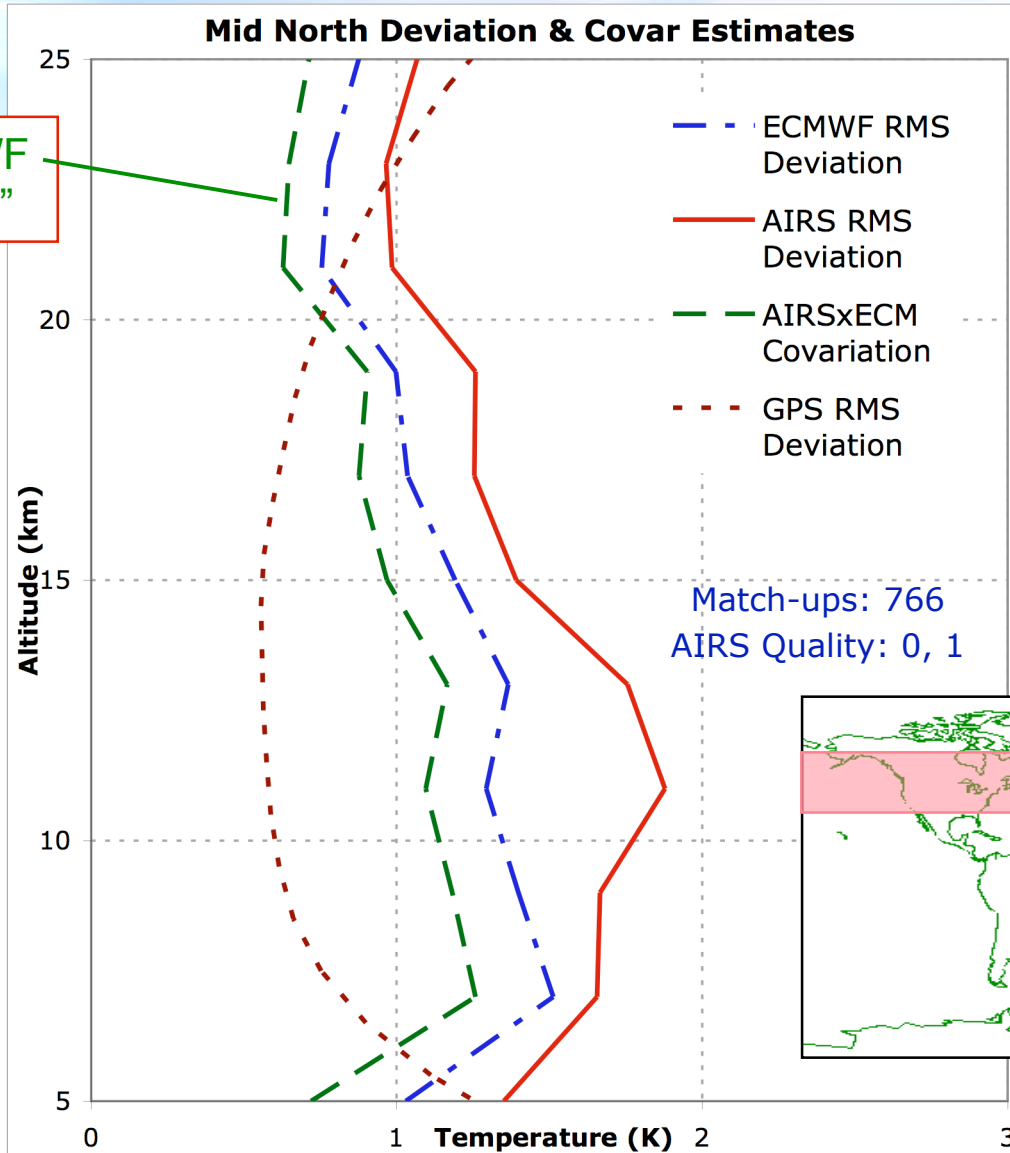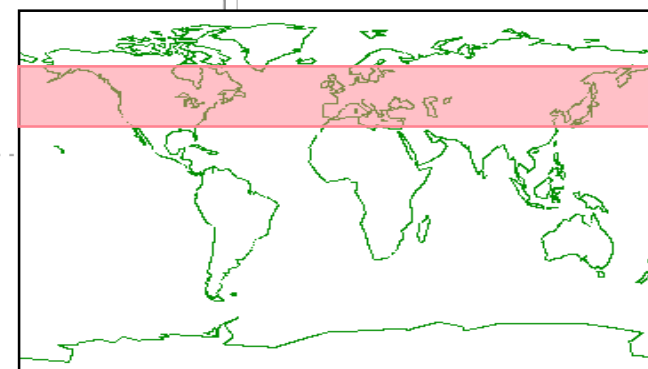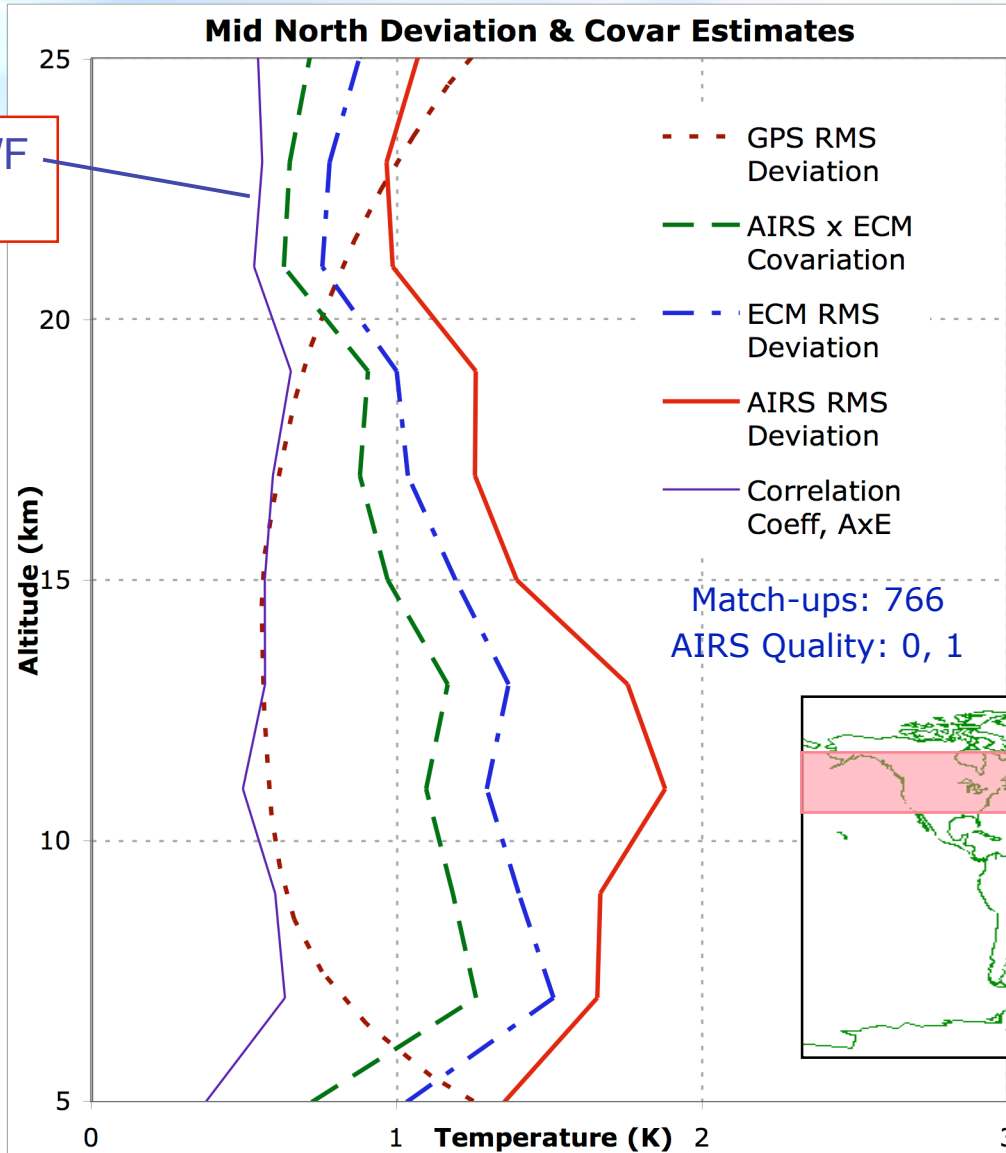
How else can we examine this question?

Compare regional performance variations, where a particular technique is known to vary in a particular way

I – The Tropics
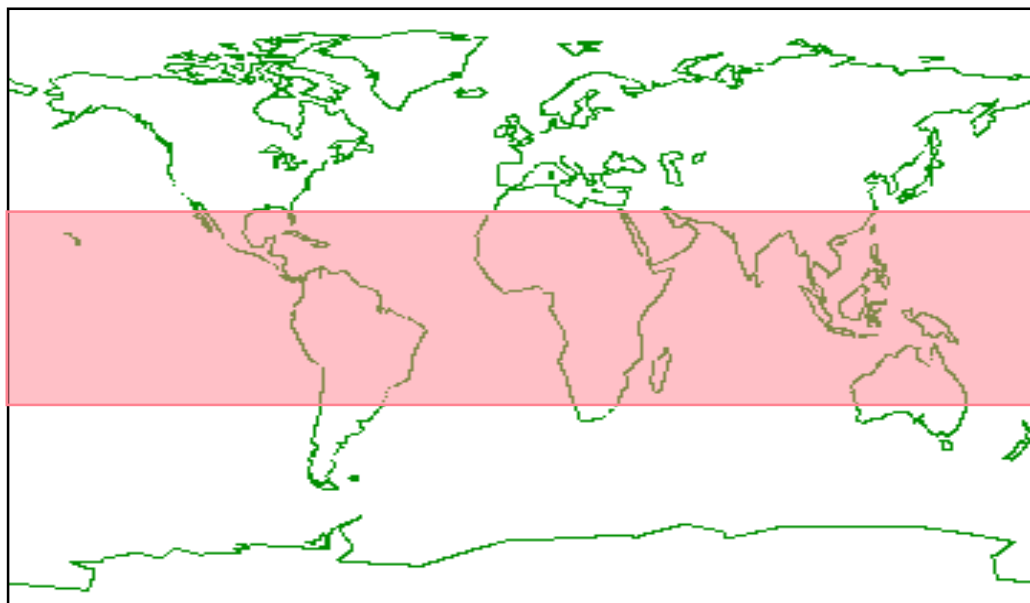
ECMWF-GPS RMS Deviations, 2003
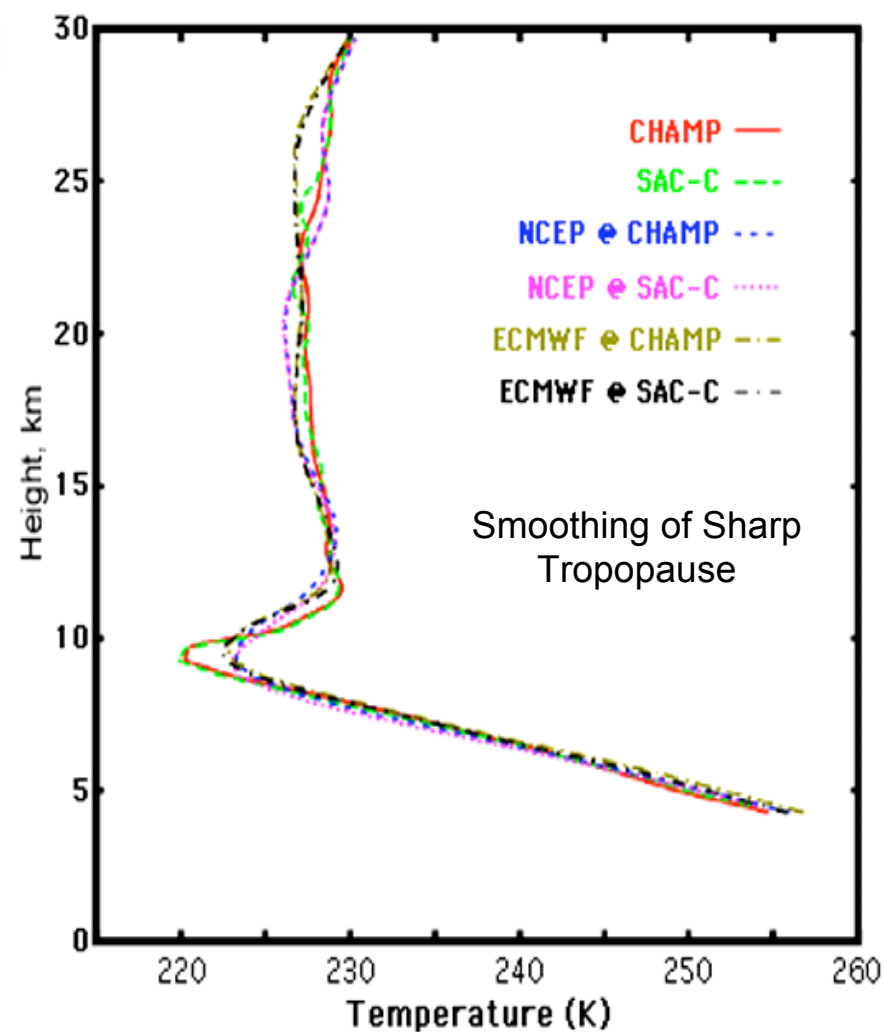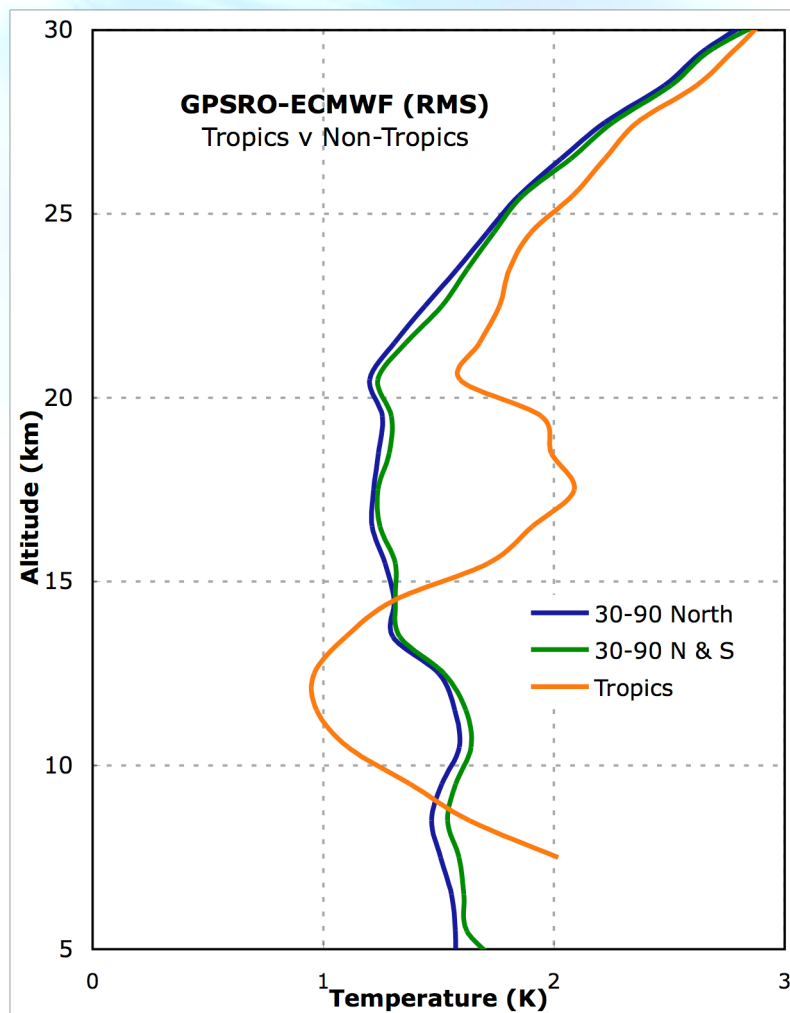
ECMWF-GPS RMS Deviations and Means, 2003
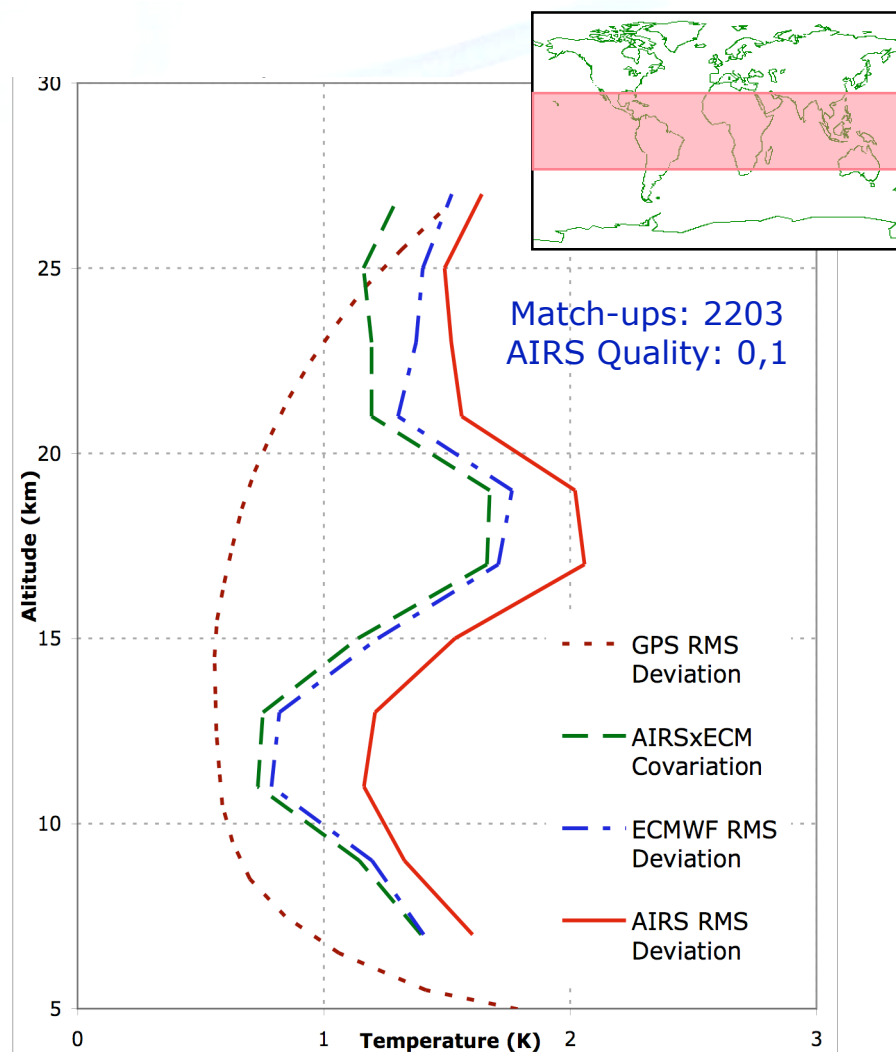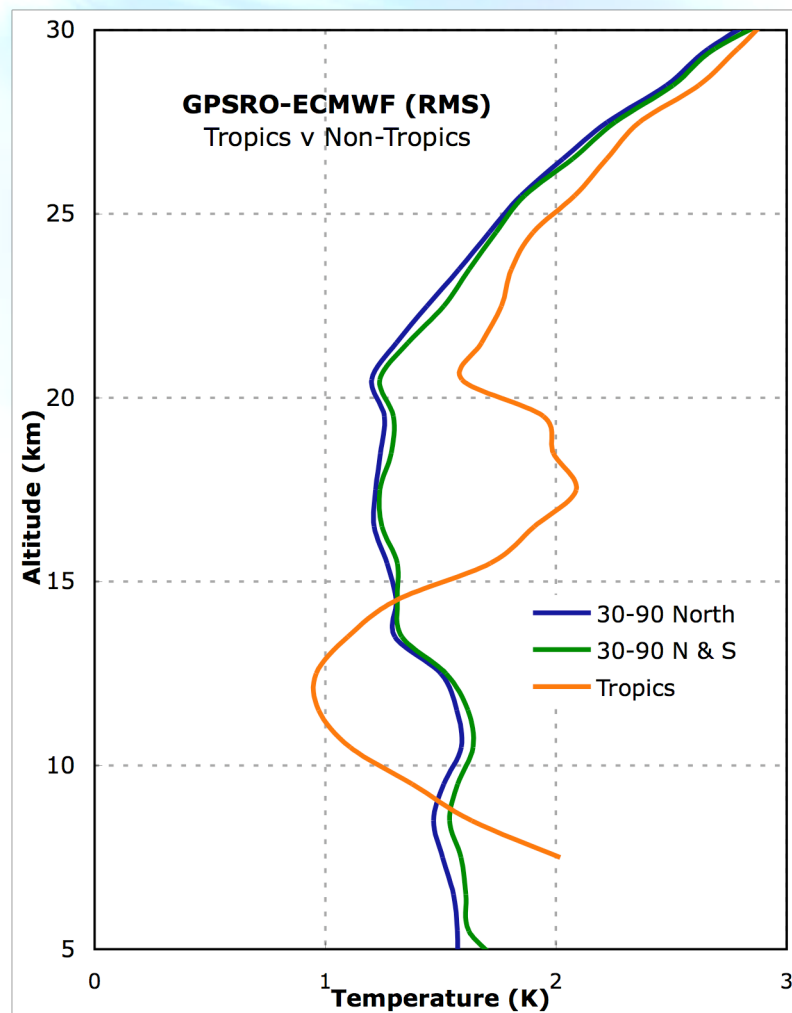
Regional Performance Variations – II

Vertical Bias Patterns
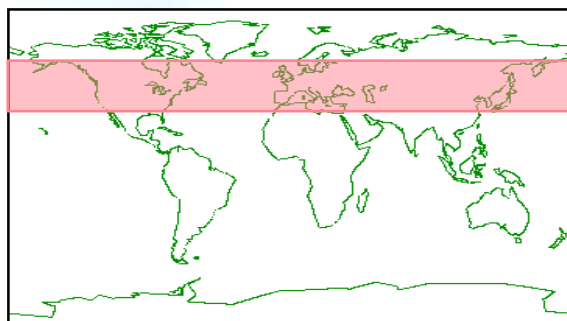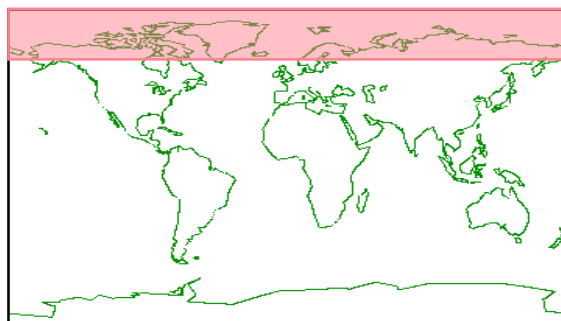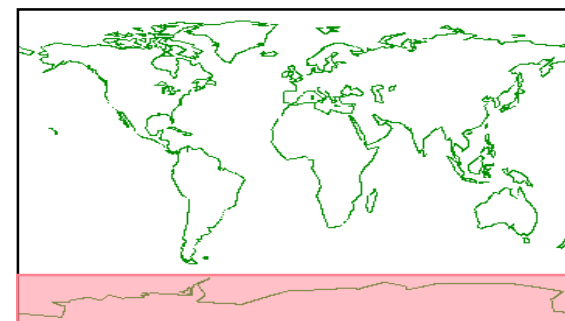
Mid North	Far North	Far South

ECMWF-GPS Means, All GPS, 2003
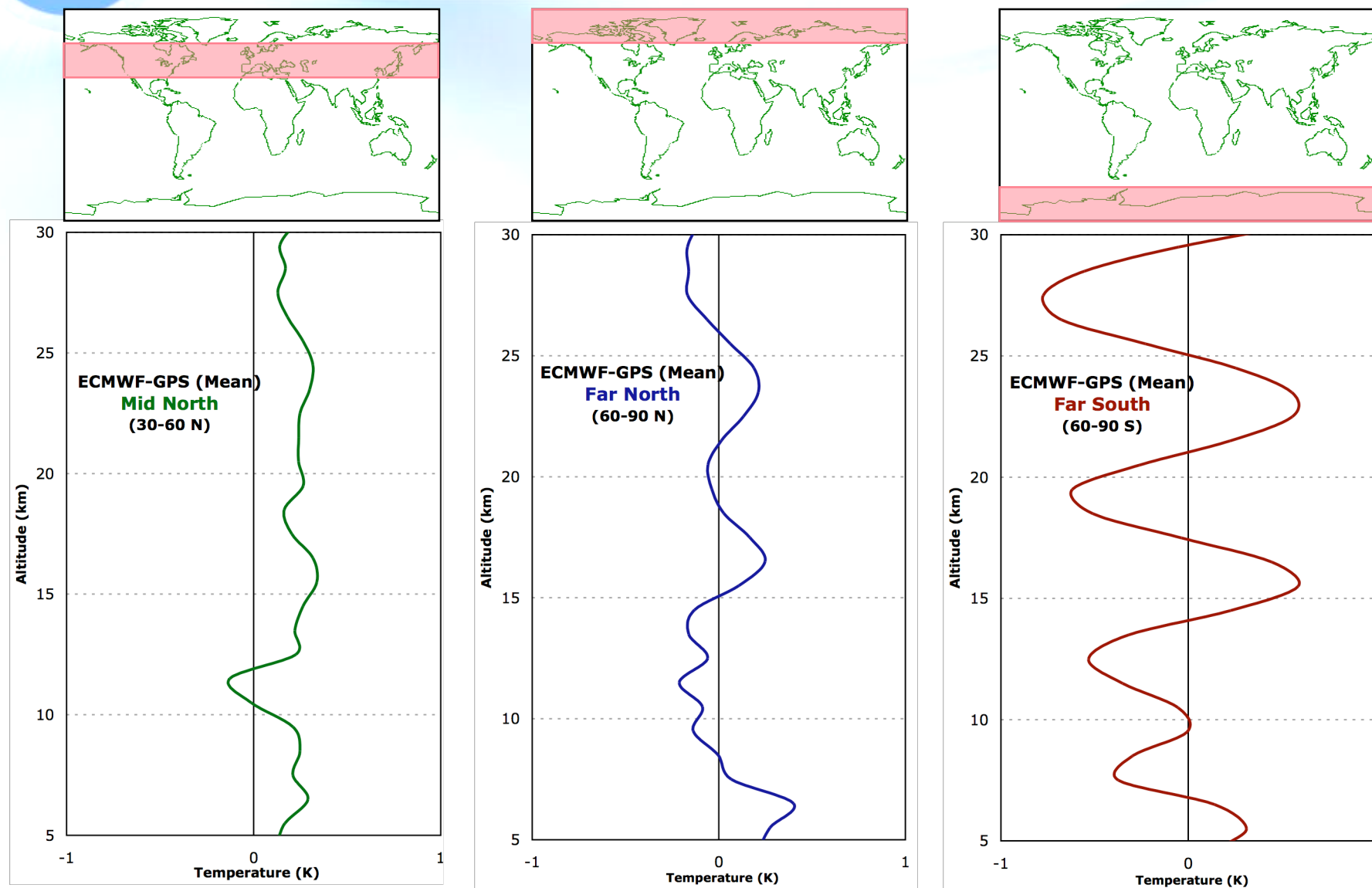
ECMWF & AIRS Means vs GPS, All 2003
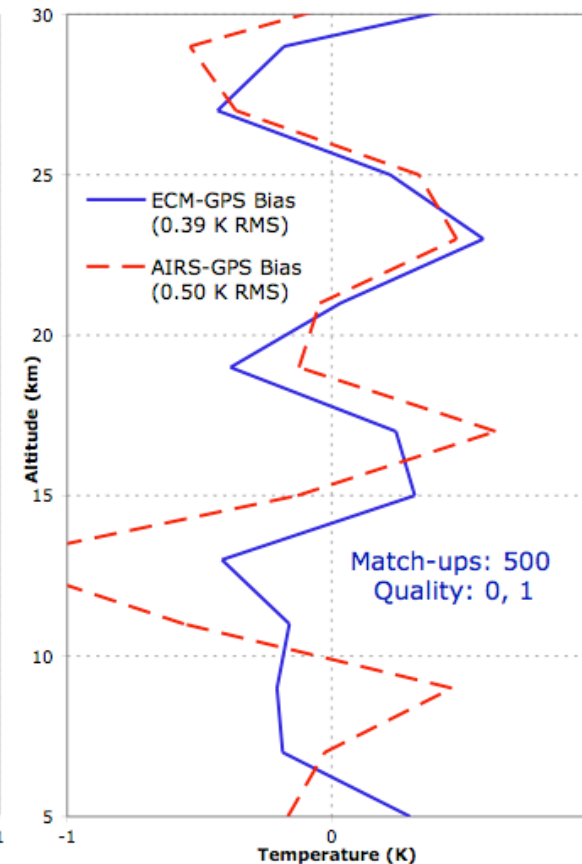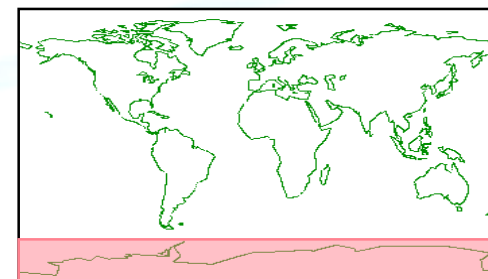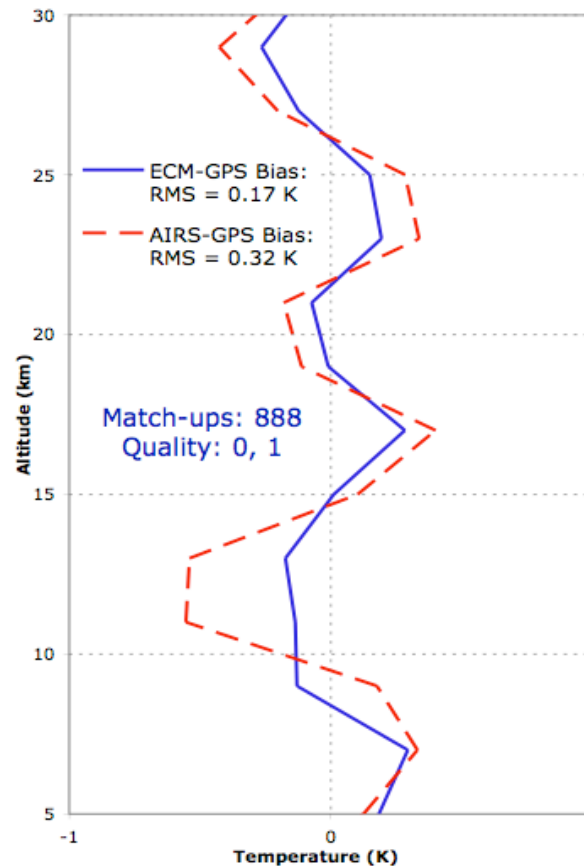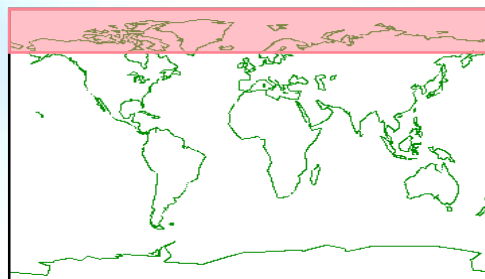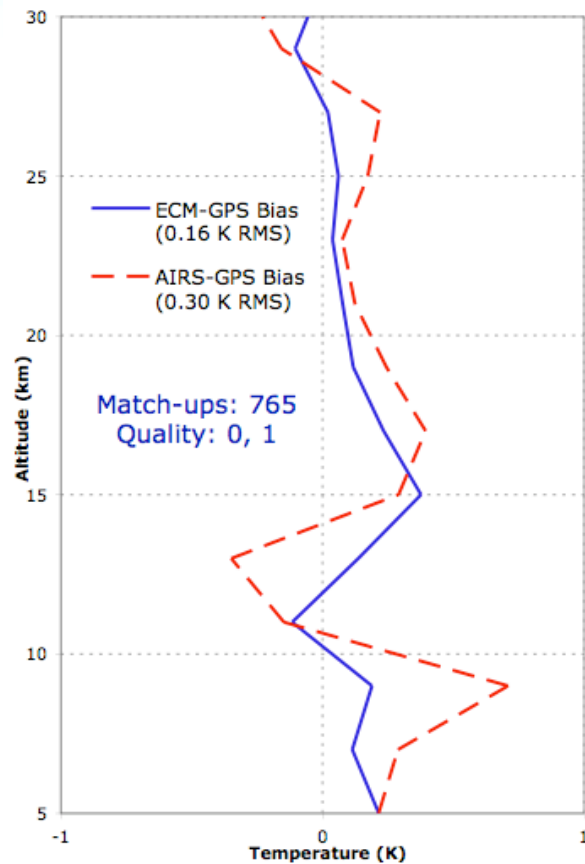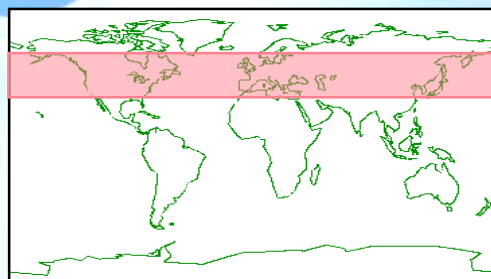
Conclusion

_IF_ our GPSRO error model is accurate, then:

3-way comparisons show significant correlation between AIRS and ECMWF temperature errors.

Caveat:

We should adopt actual AIRS smoothing functions to ensure we are comparing like quantities.

Next:

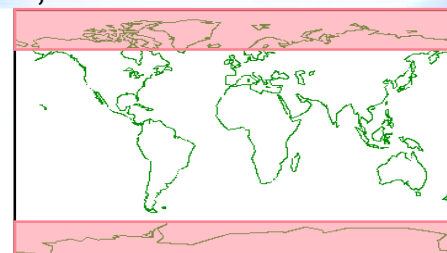Repeat the analysis with AIRS V5 and COSMIC data and true AIRS smoothing functions.
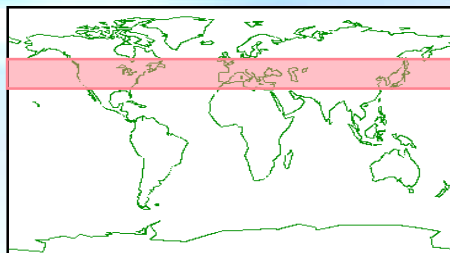
Backups
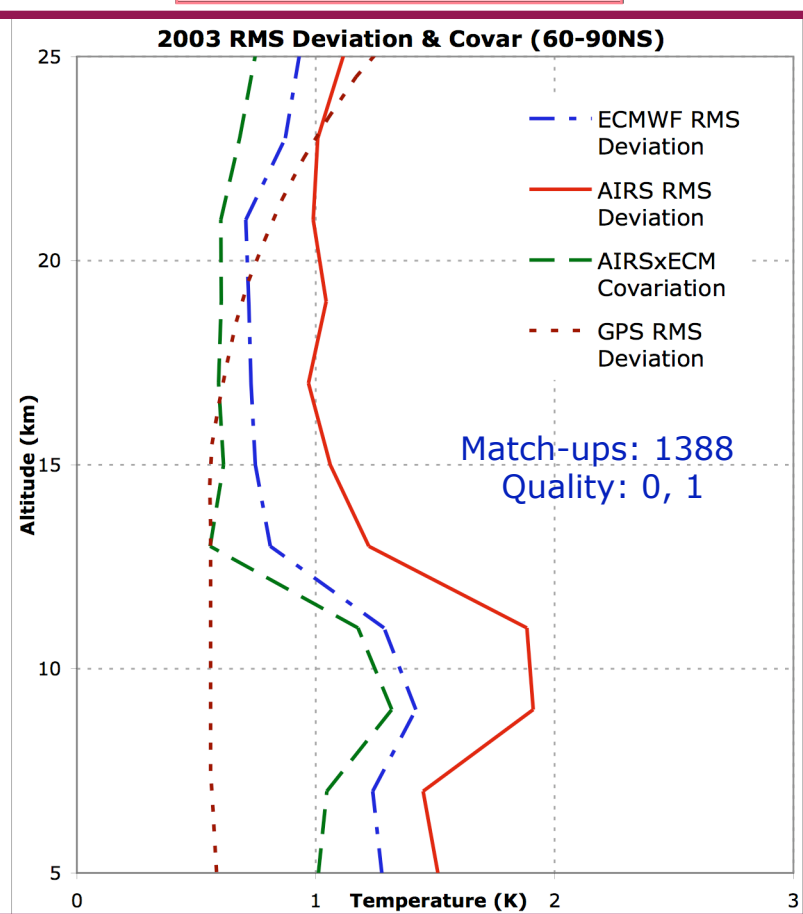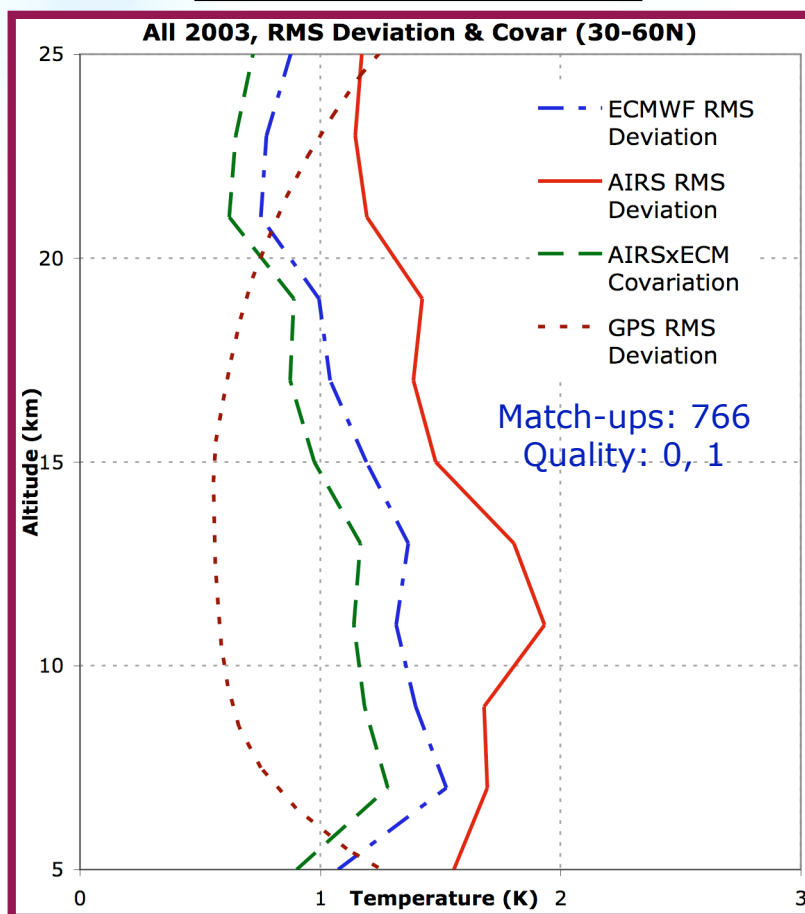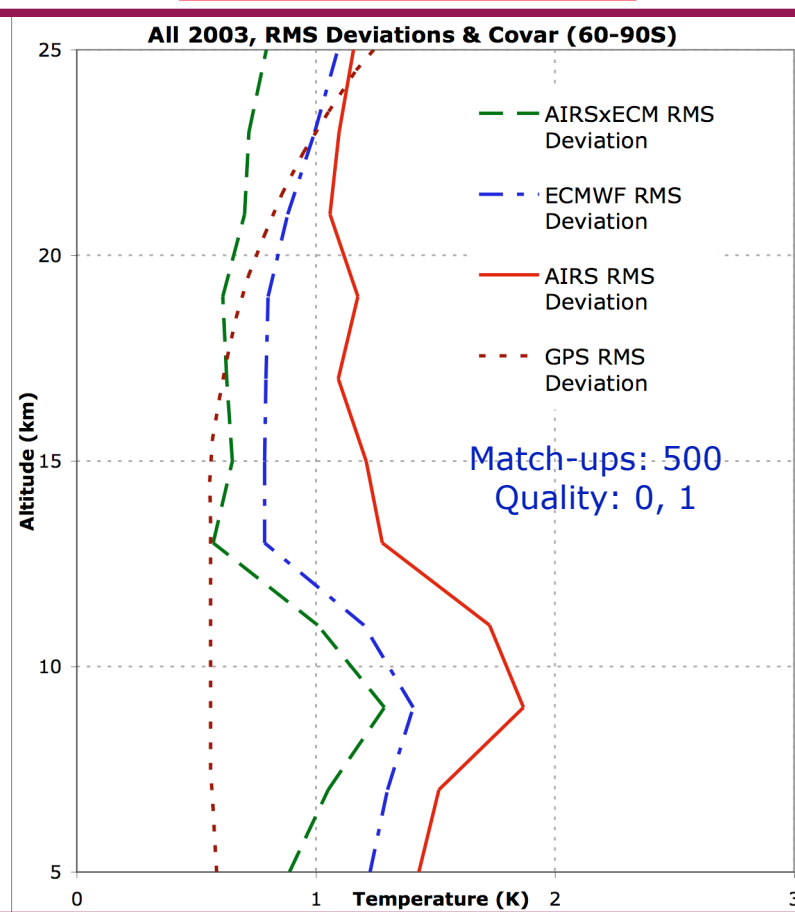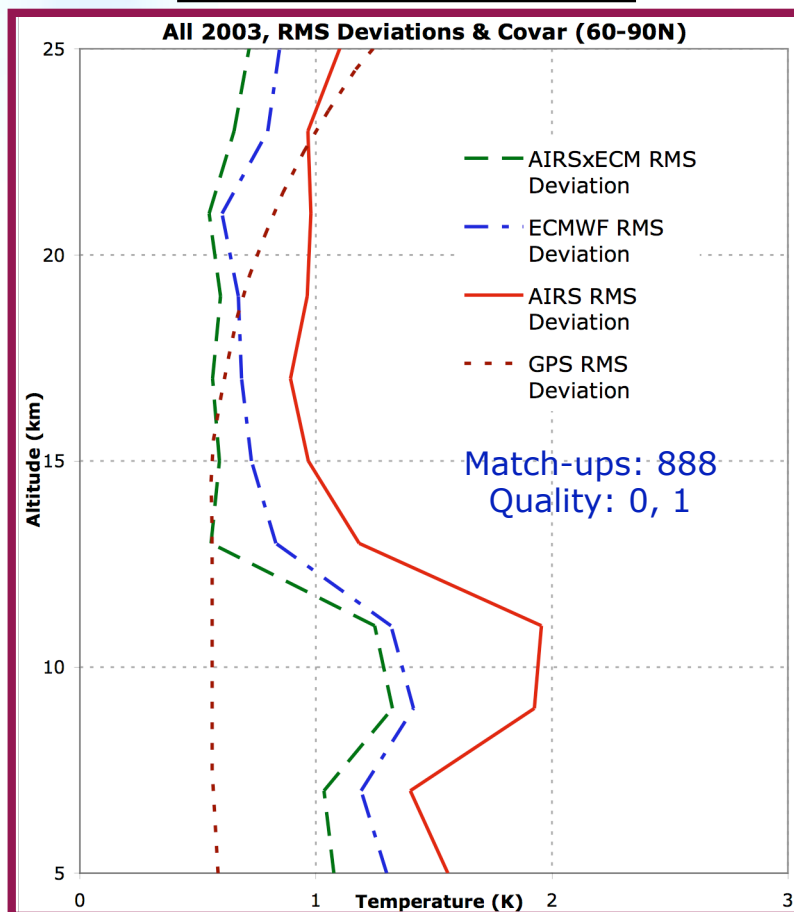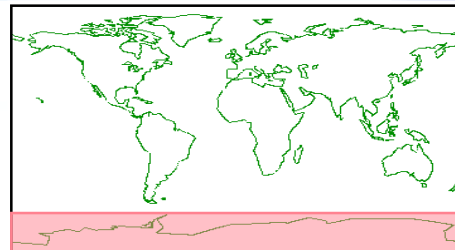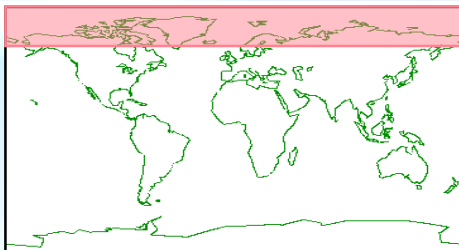
RMS Deviations & Covariation, All 2003

RMS Deviations & Covariation, All 2003

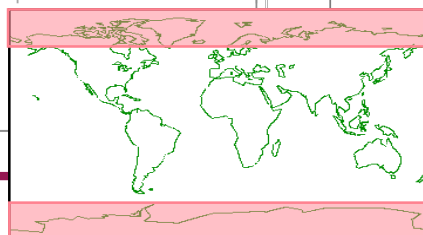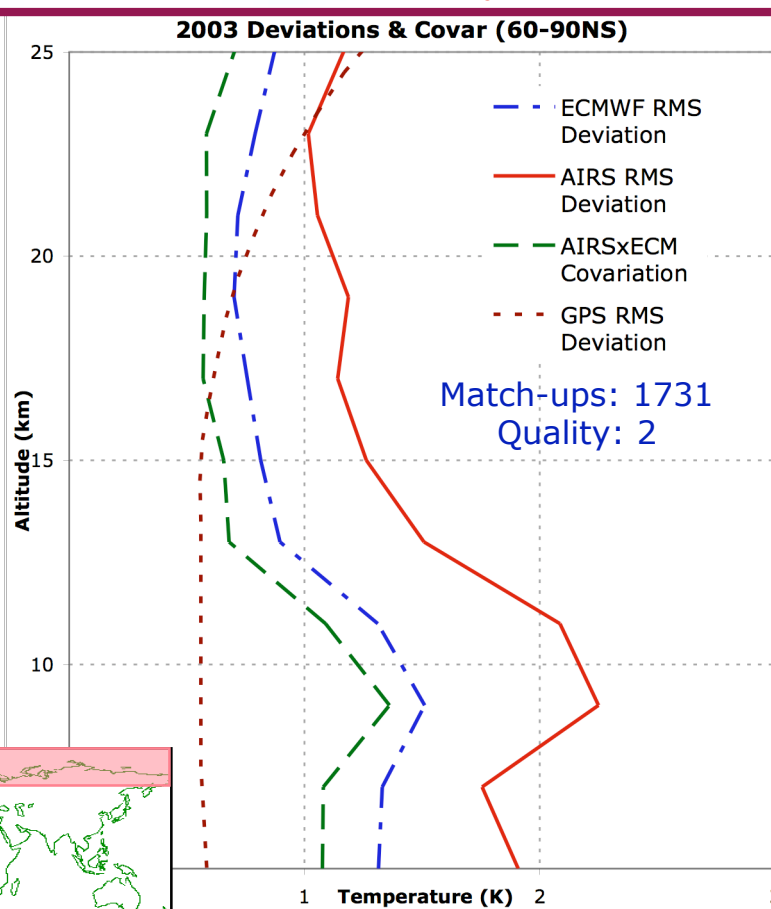## RMS Deviations & Covariation, All 2003
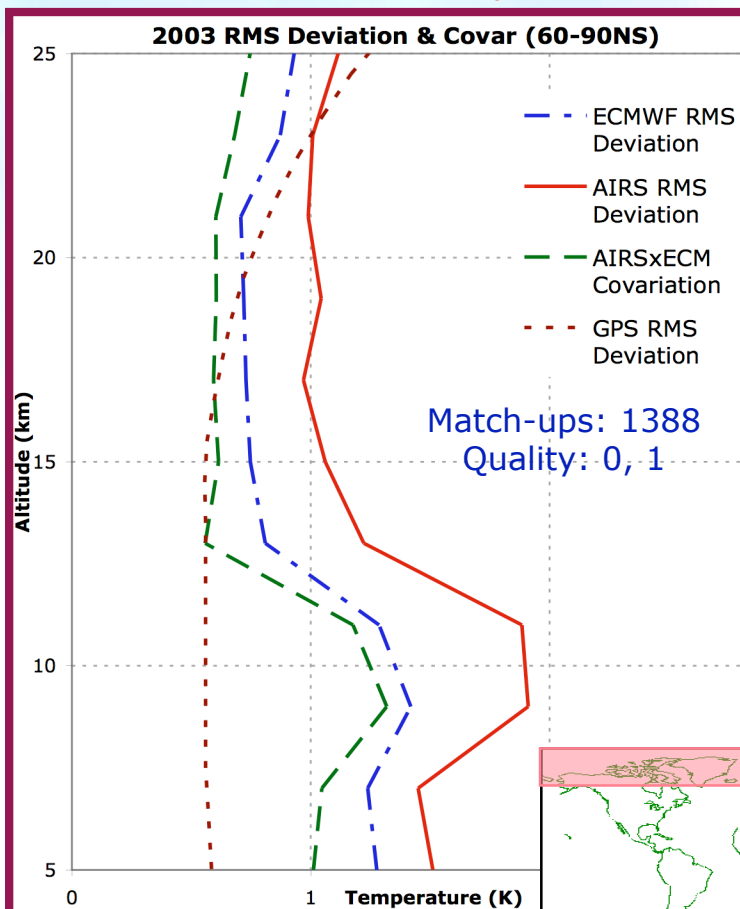
Simple Analysis

Measurement error = bias (b) + zero mean random error (e):

$$M_e = b + e$$

Measurement difference $M_1 - M_2$ is therefore:

$$M_{1,2} = b_1 - b_2 + e_1 - e_2$$

$$= b_{1,2} + e_1 - e_2$$

The mean (expected) squared (MS) difference is therefore:

$$MS_{1,2} = b_{1,2}^2 + \sigma_1^2 + \sigma_2^2$$

(assuming e_1 and e_2 uncorrelated)

Or:

$$MS_{1,2} - b_{1,2}^2 = \sigma_1^2 + \sigma_2^2$$

(i.e., Var = MS - square of the mean)

For the three-way comparison we have:

(1) $MS_{1,2} - b_{1,2}^2 = \sigma_1^2 + \sigma_2^2$

(2) $MS_{2,3} - b_{2,3}^2 = \sigma_2^2 + \sigma_3^2$

(3) $MS_{1,3} - b_{1,3}^2 = \sigma_1^2 + \sigma_3^2$

What this means:

Measurement difference $M_1 - M_2$ is:

$$M_{1,2} = b_{1,2} + e_1 - e_2$$

The mean squared (MS) difference is:

$$MS_{1,2} = b_{1,2}^2 + \sigma_1^2 + \sigma_2^2 - 2E[e_1 e_2]$$

~~(assuming e_1 and e_2 uncorrelated)~~

Revised Analysis
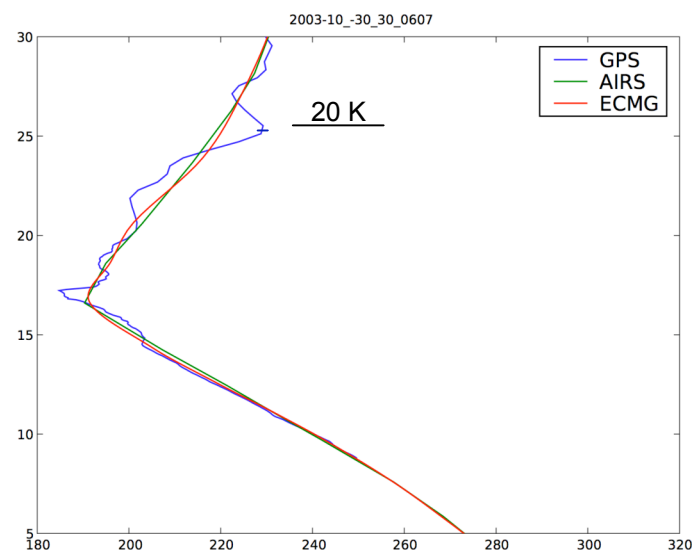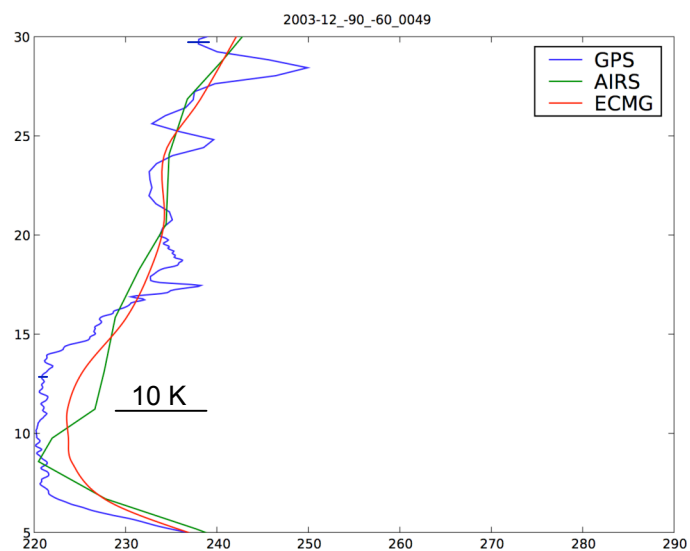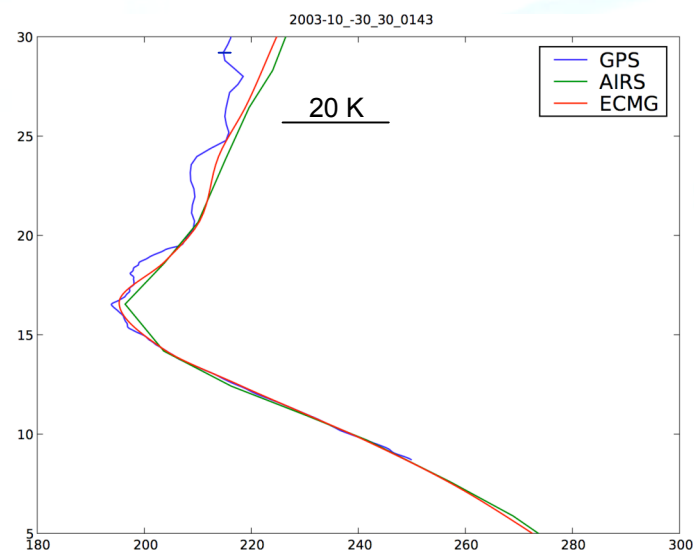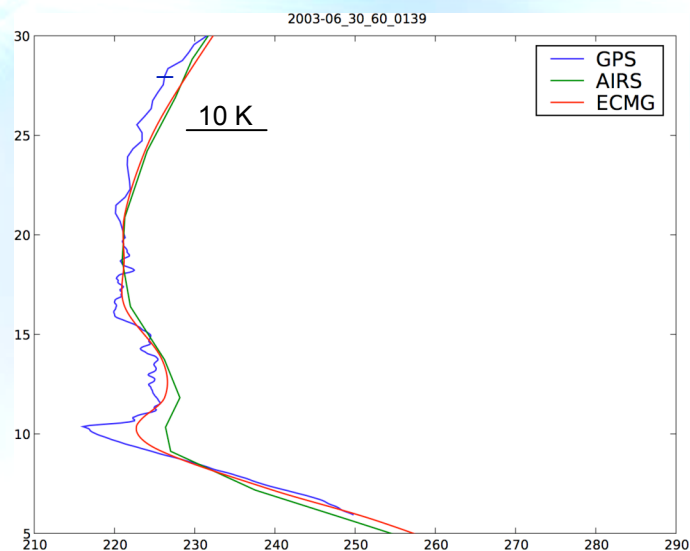
For the three-way comparison we now have:

$$(1) \quad MS_{E,A} - b_{E,A}^2 = \sigma_E^2 + \sigma_A^2 - 2\gamma_{E,A}^2$$

$$(2) \quad MS_{A,G} - b_{A,G}^2 - \sigma_G^2 = \sigma_A^2$$

$$(3) \quad MS_{E,G} - b_{E,G}^2 - \sigma_G^2 = \sigma_E^2$$

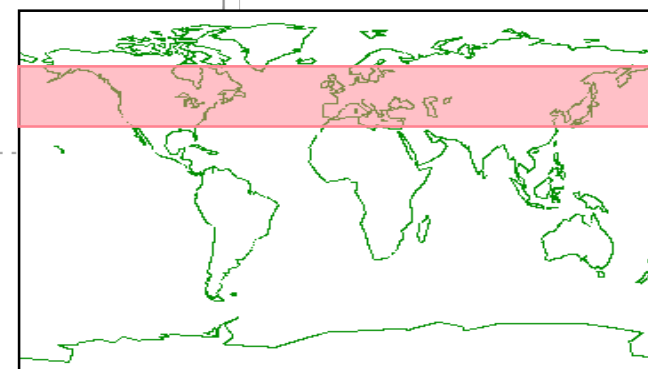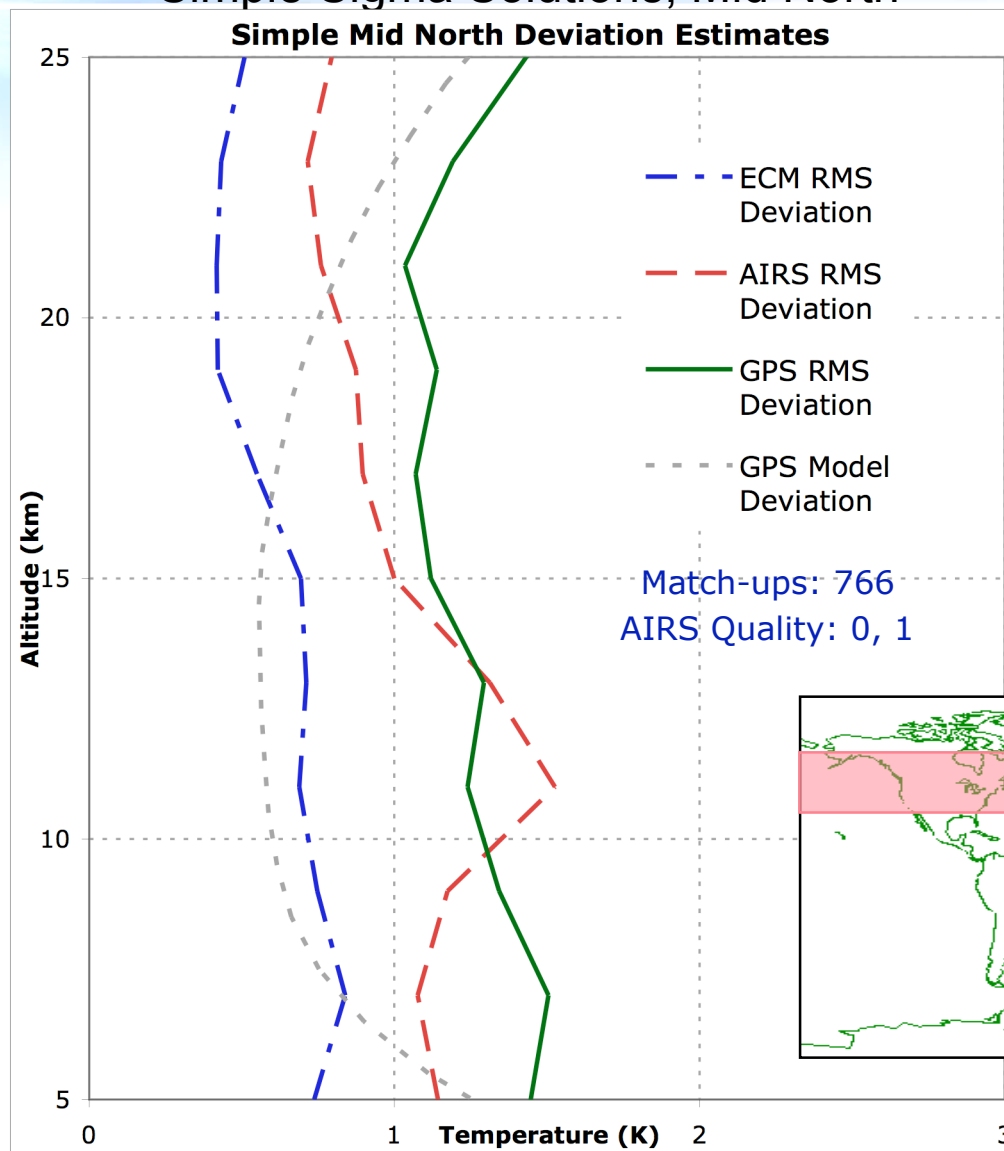# Examples of AIRS-ECMWF Temperature Error Similarity

Working Hypothesis

1. AIRS "first guess" temperatures, *trained on ECMWF model*, closely reproduce location-dependent ECMWF bias characteristics.

2. Where temperature gradients are small, AIRS retrieval information is weak and departures from the first guess are small.

3. This leads to significant correlation in location-dependent biases.

4. Where temperature gradients are steep (near the tropopause), AIRS retrievals are allowed to depart more from the a priori, reducing the AIRS-ECMWF correlation.
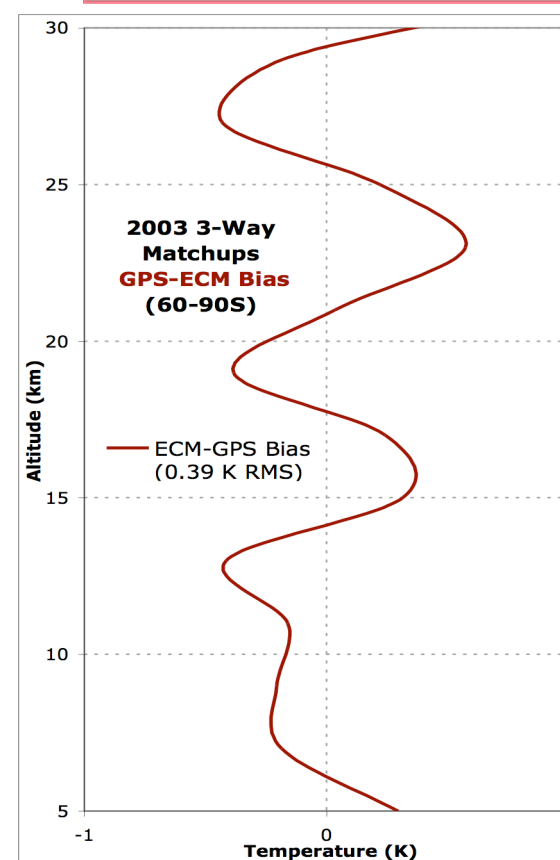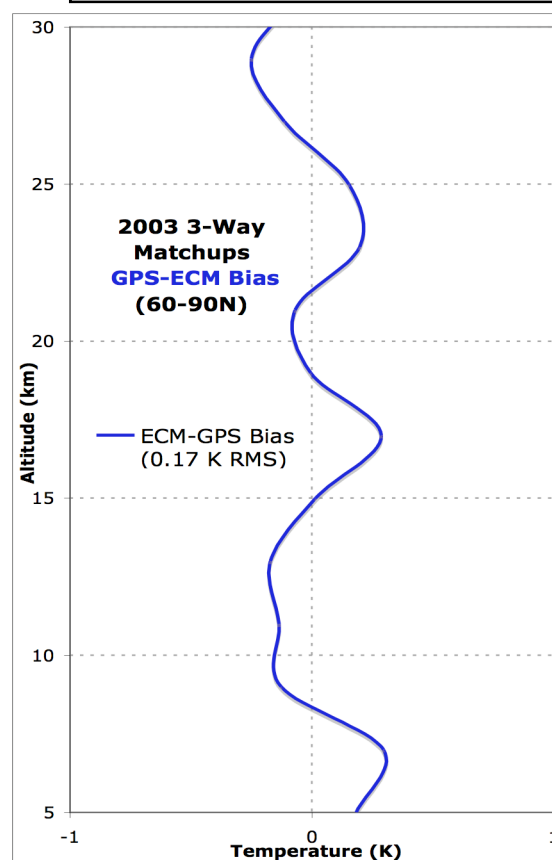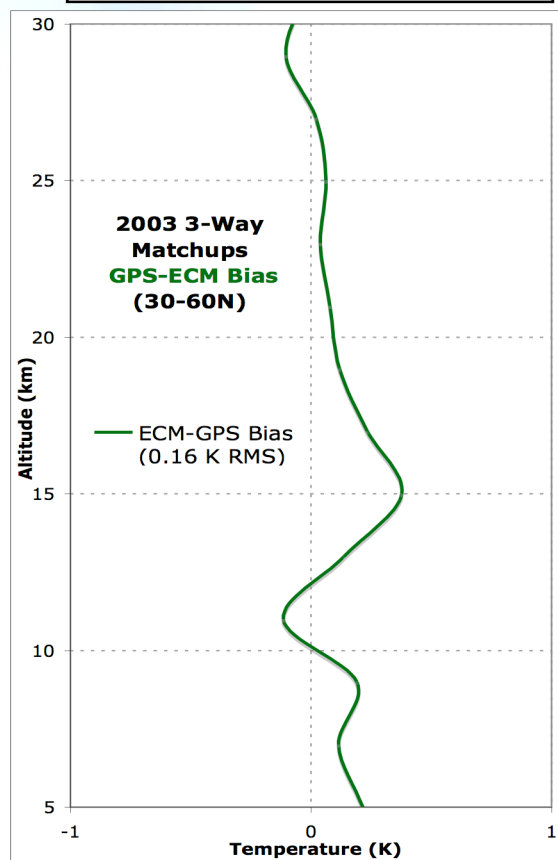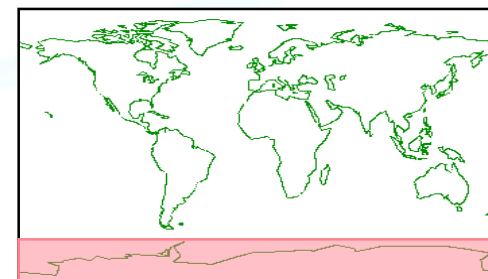
Simple Sigma Solutions, Mid North

Simple Mid North Deviation Estimates

Match-ups: 766
AIRS Quality: 0, 1

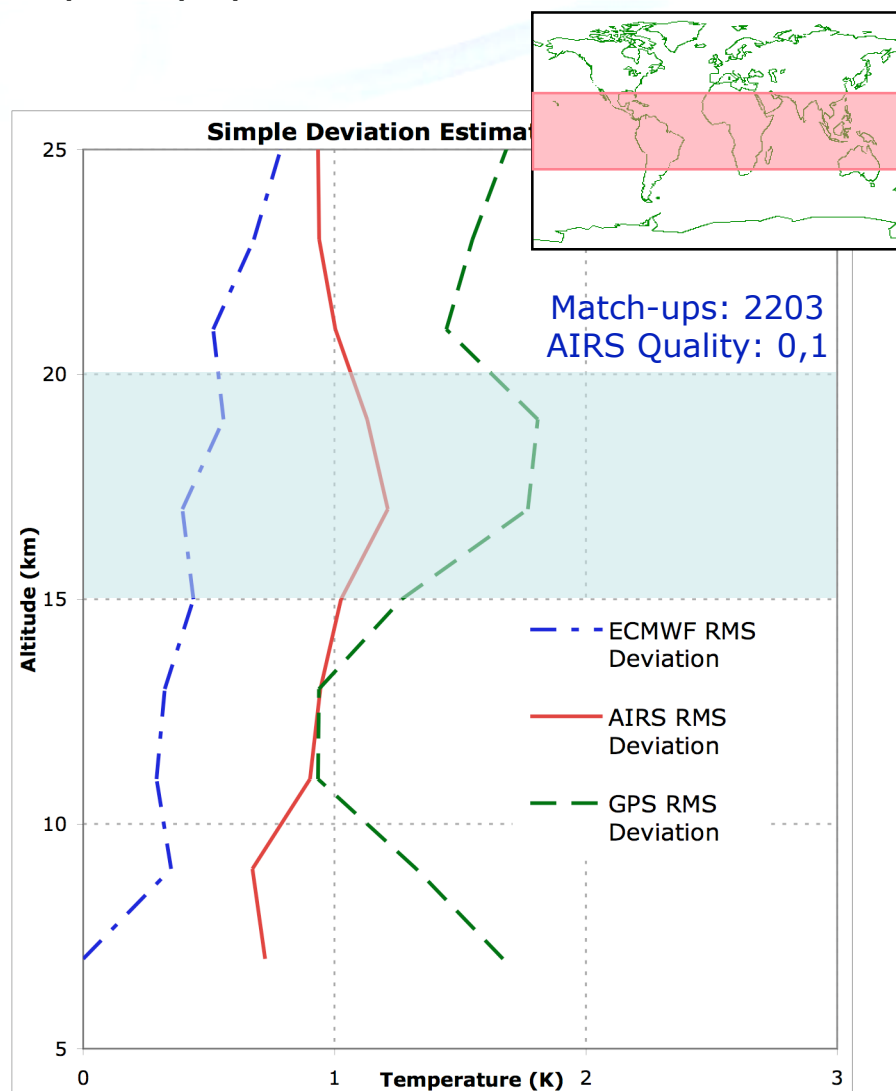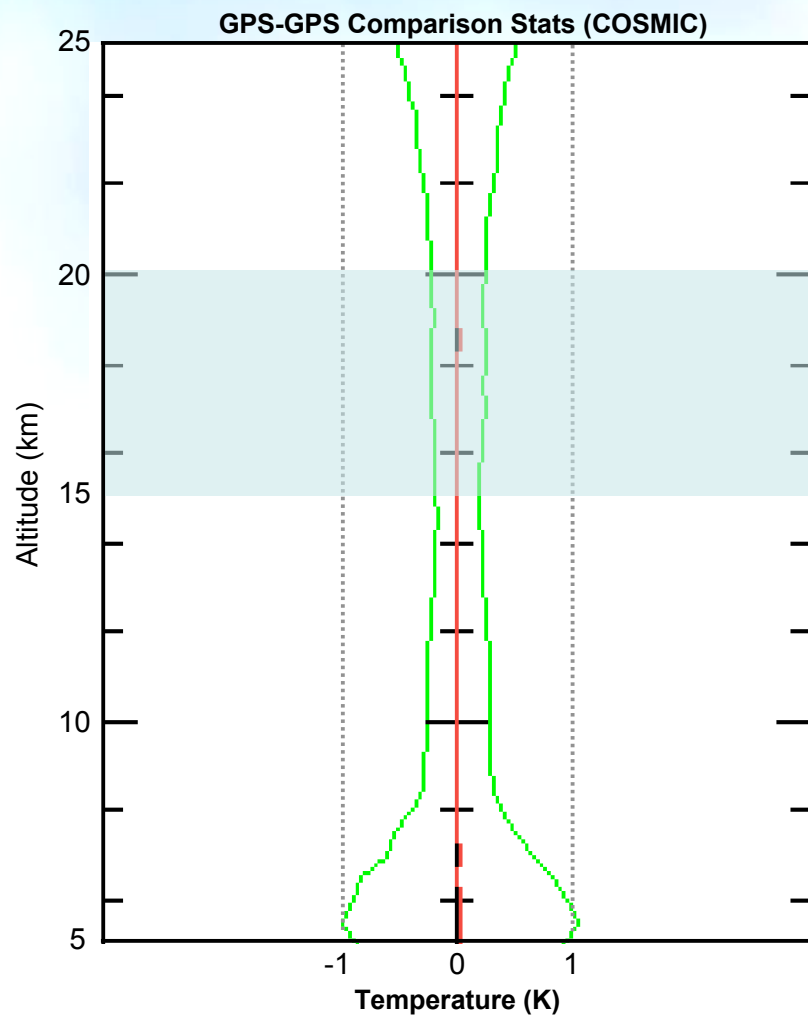# ECMWF-GPS Means, 3-Way Matchups, 2003
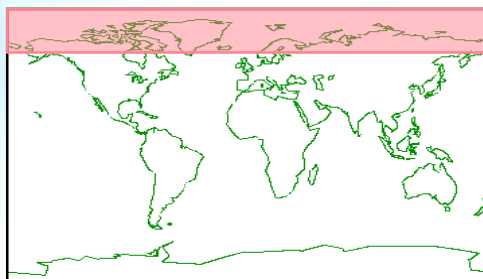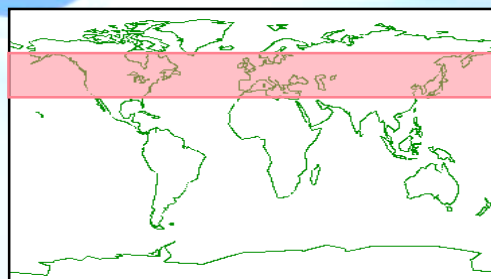
Smoothing of Sharp Tropopause

Match-ups: 2203
AIRS Quality: 0,1

Typical 3-Way Matchup

2003-09_-30_30_0030

GPS
AIRS
ECM

For consistent comparisons
GPS & AIRS were smoothed
to 2 km vertical resolution